

Method for forming a hardened cement in a bone cavity

Cross-reference to Related Application

The present application is a continuation-in-part application of U.S. Patent Application Serial Number 10/393,044, filed March 21, 2003. The above-listed application is commonly assigned with the present invention and the entire contents of which are incorporated herein by reference.

Field of the Invention

The present invention is related to a technique of forming a set or hardened bone cement in bone cavity, and in particular to a technique of hardening a bone cement under an exerted pressure in a bone cavity.

Background of the Invention

A calcium phosphate cement (abbreviated as CPC) has been widely used as an implant or filling material in dental and bone prosthesis, and its technical details can be found in many patents, for examples US patent numbers 4,959,104; 5,092,888; 5,180,426; 5,262,166; 5,336,264; 5,525,148; 5,053,212; 5,149,368; 5,342,441; 5,503,164; 5,542,973; 5,545,254; 5,695,729 and 5,814,681. Similar to CPC, calcium sulfate and bioactive glass have also been suggested or used as an implant or filling material in dental and bone prosthesis.

Heretofore the conventional method of forming a set or hardened bone cement in bone cavity involves directly injecting a cement paste into bone cavity, which suffers the followings drawbacks among others:

- (1) While the liquid-powder ratio of the cement paste is too high, the strength of the hardened cement becomes too low, that can cause the cement to more easily disperse/disintegrate;
- (2) While the liquid-powder ratio of the cement paste is too low, the viscosity of the paste becomes too high, the working and setting times become too short, and the paste is hard to inject through a syringe;
- (3) Dispersed cement particles in body fluid/blood, especially before being fully set, can penetrate into surrounding tissue, that can cause serious

hazard during or after surgery.

Summary of the Invention

A primary objective of the present invention is to provide a method for
5 forming a hardened cement in a bone cavity, which are free of the
aforesaid prior art drawbacks.

The method disclosed in the present invention comprises the
following steps:

- a) preparing a cement paste from a powder and a liquid, so that said
10 cement paste is injectable through a syringe;
- b) disposing a pocket in a bone cavity; said pocket is made from a
material penetrable to said liquid but substantially impenetrable to the
powder of said cement paste;
- c) injecting said cement paste into said pocket;
- 15 d) applying a pressure unto said cement paste before said cement
paste is substantially hardened, causing a portion of said liquid to be
squeezed out of said pocket, so that the powder/liquid ratio of said cement
paste in said pocket is increased; and
- e) allowing said cement paste to harden in said pocket.
- 20 Preferably, said method further comprises:
 - f) opening said pocket; and
 - g) separating the resulting opened pocket from the hardened cement.

More preferably, said injecting in step c) and said opening in step f) is
carried out with a means which is able to be operated outside said bone
25 cavity, and the resulting opened pocket is attached to said means.

Further, said separating in step g) is preferably carried out by removing
the resulting opened pocket from said bone cavity with the hardened
cement remaining in said bone cavity.

Preferably, said pocket is made from a fiber cloth or a polymer foil.
30 More preferably, and said fiber cloth is biodegradable, and said method
further comprises leaving the hardened cement resulting from step e)
together with the pocket in said bone cavity.

Preferably, said pocket is made from a fiber cloth or a polymer foil,

wherein said opening in step f) comprises cutting at least a portion of said pocket with a blade or a thin wire.

Preferably, wherein said pocket is made from a fiber cloth, wherein said opening in step f) comprises loosening or unthreading at least a
5 portion of said fiber cloth.

Preferably, said means comprises a syringe tube having an injection end; a mounting mechanism at said injection end for mounting said pocket to said injection end; a first set of wire holders on an outer surface of said syringe, which are spaced apart along a longitudinal direction of said
10 syringe; a second set of wire holders on said outer surface of said syringe, which are spaced apart along said longitudinal direction of said syringe, wherein an imaginary plane formed by said first set of wire holders and said second set of wire holders divides the syringe into halves; and said thin wire which is slidably received said first set of wire holders and said
15 second set of wire holders with a portion thereof passing across said injection end of said syringe. More preferably, said means further comprises a thin tube on said outer surface of said syringe along said longitudinal direction of said syringe; and said blade slidably received in said thin tube, said blade having a retractable blade and a rod connected
20 to said retractable blade at one end thereof, so that said retractable blade received in said tube is able to protrude from said injection end of said syringe by pushing the rod, and thus said pocket can be cut by said retractable blade, and that said protruding retractable blade can be retracted by pulling the rod.

25 Alternatively, said means comprises a syringe having an injection end; a mounting mechanism at said injection end for mounting said pocket to said injection end; a thin tube on an outer surface of said syringe along a longitudinal direction of said syringe; and said blade slidably received in said thin tube, said blade having a retractable blade and a rod connected
30 to said retractable blade at one end thereof, so that said retractable blade received in said tube is able to protrude from said injection end of said syringe by pushing the rod, and thus said pocket can be cut by said retractable blade, and that said protruding retractable blade can be

retracted by pulling the rod.

Preferably, said mounting mechanism of said means comprises an annular groove formed on said outer surface of said syringe and an elastic ring having a shape and size corresponding to those of said annular
5 groove, so that a neck of said pocket can be clamped by said elastic ring received in said annular groove of said syringe after said injection end of said syringe being inserted into an opening of said pocket.

Preferably, said pressure in step d) is of about 0.1-200 MPa. More preferably, said pressure is of about 0.5-50 MPa. Said pressure is
10 measured in-situ with a pressure sensor.

Preferably, said cement paste comprises a calcium phosphate-based cement, a calcium sulfate-based cement, or a bioactive glass-based cement.

The present invention solves the aforesaid prior art drawbacks,
15 because the cement paste set within the closed pocket without contacting directly body fluid/blood, and pressure can be applied/developed within the pocket, which will increase largely the strength of the cement, reduces the risk of cement dispersion/disintegration, and also avoid "cement paste leaking".

20 Further, the present invention has an advantage of being easy to keep a powder/liquid ratio of the cement paste accurate by monitoring the pressure build-up within the pocket, that is important to cement properties such as setting time and strength.

25 Brief Description of the Drawings

Figs. 1A to 1E are cross-sectional views of a device for forming a hardened cement in a bone cavity constructed according to a first preferred embodiment of the present invention, and together show a process flow diagram of the method of the present invention.

30 Fig. 2 is a cross-sectional view of a device for forming a hardened cement in a bone cavity constructed according to a second preferred embodiment of the present invention.

Detailed Description of the Preferred Embodiments

A device for forming a hardened cement in a bone cavity constructed according to a first preferred embodiment of the present invention is shown in Figs. 1A and 1B. The device contains a syringe 10 having a substantially cylindrical tube 11 and a plug 12 slidably received in the tube 11; and a mounting mechanism 20 having an annular groove 21 provided on an outer surface of the tube 11 and near an injection end of the syringe, and a ring 22 adapted to elastically grip the annular groove 21. A pocket 30, preferably an inflatable and expandable or non-expandable pocket made of a fiber cloth is used, is mounted to the injection end of the syringe by inserting the injection end into an opening of the pocket 30, so that a neck 31 of the pocket 30 covers the annular groove 21; and putting the ring 22, which is a closed ring or a C-shaped ring, on the neck 31 of the pocket 30 and clamping it at the annular groove 21 on the cylindrical tube 11.

The device further contains a first set of wire holders 40 on the outer surface of the cylindrical tube 11 and along the longitudinal direction thereof; and a second set of wire holders 41 on the outer surface of the cylindrical tube 11, which are symmetrical to the first set of wire holders 40; and a thin wire 50 slidably received in the first and second sets of wire holders 40 and 41. The wire holders 40 and 41 are blocks each having a through hole, through which the thin wire 50 is passed and guided longitudinally. Preferably, the device further has two tension-adjustable rollers 42 and 43, on which the ends of the thin wire 50 are wound, so that the thin wire 50 is maintained in the first set and second set of wire holders 40 and 41 under a controlled tension. The device of the present invention is now ready to be used. The injection end of the syringe 10 is inserted into a bone cavity through an incision cut and a hole drilled by the operator. As shown in Fig. 1B, a cement paste, preferably a CPC paste giving a setting time less than 20 minutes, more preferably less than 10 minutes, is injected into the pocket 30 by pushing the plug 12 in the tube 11 toward the injection end of the syringe, so that the pocket 30 is inflated and the portion of the thin wire 50 passing across the injection

end is pushed, and thus the thin wire 50 is un-wound from one or both of the rollers 42 and 43 until all the CPC paste is injected into the pocket 30. The CPC paste in the pocket 30 is maintained under the pressure exerted by the plug 12 while setting, and preferably the pressure is about 1-5000
5 psi, and more preferably 10 – 1000 psi. The thin wire 50 is pulled forward and backward alternatively at its ends under tension to cut the pocket 30 after the CPC paste is hardened in the pocket 30, as shown in Figs. 1C-1D. One end of the thin wire 50 is released from the roller 42 by continuously pulling the thin wire 50 with the roller 43, after the pocket
10 30 is cut open, as shown in Fig. 1D. Finally the hardened CPC is left in the bone cavity by retreating the device together with the opened pocket 30 from the patient, as shown in Fig. 1E.

The cutting of the pocket 30 can be carried out by a different cutting structure. Fig. 2 shows a modified device of the present invention based
15 on the design shown in Figs. 1A-1E, wherein like elements or parts are represented by like numerals. A thin tube 60 is provided on the outer surface and along a longitudinal direction of the cylindrical tube 11 of the syringe 10. A blade 70 having a rod 71 and a retractable blade 72 is slidably received in the thin tube 60 by inserting the rod 71 into the thin
20 tube 60 from the end near the injection end of the syringe 10 until the retractable blade 72 enters the thin tube 60. The retractable blade 72 is preferably made of metal and is elastic, so that it resumes its shape after being pushed to protrude from the thin tube 60. The operator can grip the rod 71 from the other end of the thin tube 60 to push the retractable
25 blade 72 to protrude from the thin tube 60, cut the pocket 30 with the retractable blade 72, and retract it once again.

It is apparent that the cutting structure shown in Fig. 2 can be incorporated to the device shown in Figs. 1A-1E to assure a successful cutting of the pocket.

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PREPARATIVE EXAMPLE: Preparation of non-dispersive TTCP/DCPA-based CPC powder (abbreviated as ND-CPC)

A $\text{Ca}_4(\text{PO}_4)_2\text{O}$ (TTCP) powder was prepared by mixing $\text{Ca}_2\text{P}_2\text{O}_7$

powder with CaCO_3 powder uniformly in ethanol for 24 hours followed by heating to dry. The mixing ratio of $\text{Ca}_2\text{P}_2\text{O}_7$ powder to CaCO_3 powder was 1:1.27 (weight ratio) and the powder mixture was heated to 1400°C to allow two powders to react to form TTCP.

- 5 The TTCP powder prepared was sieved and blended with dried CaHPO_4 (DCPA) powder in a ball mill for 12 hours. The blending ratio of the TTCP powder to the DCPA powder was 1:1 (molar ratio). The resultant powder mixture was added to a 25 mM diluted solution of phosphate to obtain a powder/solution mixture having a concentration of 3
- 10 g powder mixture per 1 ml solution while stirring. The resulting powder/solution mixture was formed into pellets, and the pellets were heated in an oven at 50°C for 10 minutes. The pellets were then uniformly ground in a mechanical mill for 20 minutes to obtain the non-dispersive TTCP/DCPA-based CPC powder (ND-CPC). The
- 15 particles of this ND-CPC powder have whisker on the surfaces thereof.

EXAMPLE:

- To a setting solution of 1M phosphoric acid solution ($\text{pH} = 5.89$) the ND-CPC powder from PREPARATIVE EXAMPLE was added in a
- 20 liquid/powder ratio (L/P ratio) of 0.4, i.e. 4 ml liquid/10 g powder, while stirring. The resulting paste was filled into a cylindrical steel mold having a length of 12 mm and a diameter of 6 mm, and was compressed with a gradually increased pressure until a maximum pressure was reached. The maximum pressure was maintained for one minute, and then the
- 25 compressed CPC block was removed from the mold. At the 15th minute following the mixing of the liquid and powder, the compressed CPC block was immersed in a Hanks' solution for 1 day.

- The CPC paste in the mold was compressed with a maximum pressure listed in Table 1. In the course of the compression the
- 30 compression speeds were about 5 mm/min during 0~104.1 MPa; 3 mm/min during 104.1~138.8 MPa; 1 mm/min during 138.8~159.6 MPa; and 0.5 mm/min during 159.6~166.6 MPa. The liquid leaked from the mold during compression was measured, and the liquid/powder ratio was

re-calculated as shown in Table 1.

Each test group has five specimens, the compressive strength of which was measured by using a AGS-500D mechanical tester (Shimadzu Co., Ltd., Kyoto, Japan) immediately following the removal thereof from the Hanks' solution without drying. The measured wet specimen compressive strength is listed Table 1.

Table 1

Pressure for compressing the CPC paste in mold (MPa)	L/P ratio (after a portion of liquid removed)	Compressive strength (MPa)	Standard deviation (MPa)
1.4	0.25	26.4	1.4
34.7	0.185	75.3	3.9
69.4	0.172	100.4	6.8
156.2	0.161	138.0	8.2
166.6	0.141	149.2	12.9

The data in Table 1 show that the compressive strength of the CPC block increases as the liquid/powder ratio decreases during molding.

Although the present invention has been described with reference to specific details of certain embodiments thereof, it is not intended that such details should be regarded as limitations upon the scope of the invention except as and to the extent that they are included in the accompanying claims. Many modifications and variations are possible in light of the above disclosure.